A PLANAR "LEFT-HANDED" LENS FOR PLANE TEM WAVE EXCITATION IN PARALLEL PLATE SLOT ANTENNAS

Y.Weitsch
Department of Radiofrequency Technology

University of Stuttgart
e-mail :
yweitsch@gmx.de

J.M. Fernández
Department of Signals, Systems and Radiocommmunications
E.T.S.I Telecommunication
Polytechnic University of Madrid
e-mail :
jmfdez@gr.ssr.upm.es

M. Sierra Castañer
Department of Signals, Systems and Radiocommmunications
E.T.S.I Telecommunication
Polytechnic University of Madrid
e-mail :
m.sierra.castaner@gr.ssr.upm.es

***Abstract-* "Metamaterials" are artificially engineered structured materials exhibiting novel properties due to their special architecture and not because of the constituent homogeneous materials used to manufacture them. This enables to design new materials with characteristics not available in conventional materials. A parallel plate slot antenna with a planar "left-handed" lens excited via a coaxial probe is presented in this paper. This new feeding concept excites a TEM plane wave with a relatively uniform field distribution in the parallel plate waveguide and improves the aperture field illumination of the slots. This excitation allows enhancing the efficiency of these kinds of antennas. Some simulation results are presented.**

I. INTRODUCTION

Slot antennas set up on parallel plate waveguides are widely used as their design leads to high gain and high effiency. Furthermore, their fabrication process is easy and repeatable. The fundamental part which all antennas of this type have in common is the parallel plate waveguide, which distributes the desired amplitude and phase from its beginning to the radiating elements in function of the radiation pattern to synthesise. The feeding network of this version of antennas is constituted by the parallel plate waveguide in itself. Hence, the loss in the feeding system is in the range of 2 or 3 dB which is less than of models based on transmission lines like microstrip, stripline etc. [1].

As described in literature, there are many ways to excite a plane wave in a parallel plate waveguide [2]. From the construction point of view, the excitation via horn or conventional parabolic reflector is difficult to fabricate. Moreover, the excitation by rectangular waveguide fed slots or by excitation network constructed in microstrip technology does not generate a uniform plane wave TEM [4,5]. The presence of lateral metallic walls in the waveguide results in an abrupt decline of the electromagnetic field along the sidewalls of the waveguide. This fact and the ripples in the TEM mode due to the excitation points are important parameters in the design which chiefly influence the decrease in the efficiency of this kind of antennas [6, 7]. In the last two cases stated, the basic principle to generate a TEM mode is the same. N elements, used to induce the field, acts as sampling elements of this. The more excitation points are utilised the more uniform the TEM mode emerges and the less ripples of the inner field in the two plate waveguide occur.

In this article, we propose a slot antenna placed over the parallel plates with a novel form of excitation in the parallel plate waveguide by applying the newfangled structure called "metamateriales" [8]. "Metamaterials" are artificial electromagnetic multifunctional materials created to fulfil determined requirements. They present properties not commonly found in nature. These special complexes are also referred to as periodic structures of which the periodicity is a fraction of the wavelength of the incident wave. In particular, "left-handed" metamaterials exhibit a negative permittivity and permeability simultaneously, leading to a negative refractive index first derived by a theoretic speculation by Veselago in 1968 [9]. The negative refractive index of a "left-handed" medium can appear as negative while the index of refraction of the constituents still remains positive. As a matter of course, these arrangements have attracted considerably attention in the last five years since promising new applications in the field of antennas and microwaves, for example, in the design of novel types of perfect lenses [10] and in the generation of superficial plasmas in the microwave range [11]. One of the most popular applications of metamaterials belongs to the fabrication of planar lenses. In general, the shape of optical lenses is the one which defines their attributes, and for several special appliances this shape is complicated to fabricate. The advantage of these metamaterials is that they enable the construction of planar lenses which permit to focus light in tiny areas (significantly smaller than the wavelength of light). Whereas in a lens of glass the shape and the details of the surface define its characteristics, in a metamaterial, it is the size of its constituents that determines the traits of it.

With the objective to enhance the efficiency of planar slot antennas, this work presents a “left-handed” planar lens excited by a coaxial probe to feed the parallel plate waveguide. This novel form of excitation allows an improvement in the uniformity of the field distribution in the interior of the two plate waveguide. Moreover, it enlarges the aperture of the illumination of the slots. This special kind of excitation has the advantage to be simple, low cost and easy to fabricate with planar technology.

II. DESIGN OF THE FEEDING STRUCTURE

A. *Theoretic analysis of the “left-handed” lens*

The new feeding structure is a planar “left-handed” lens intersected by a conventional dielectric with a parabolic interface. The interaction between a “left-handed” medium and a conventional one with equivalent electromagnetic densities (the refractive index: $n_{ordinary}=n_{\text{"left-handed"}}$) and with parabolic interface has recently been successfully demonstrated to perform a transformation from cylindrical to plane waves and vice versa [12].

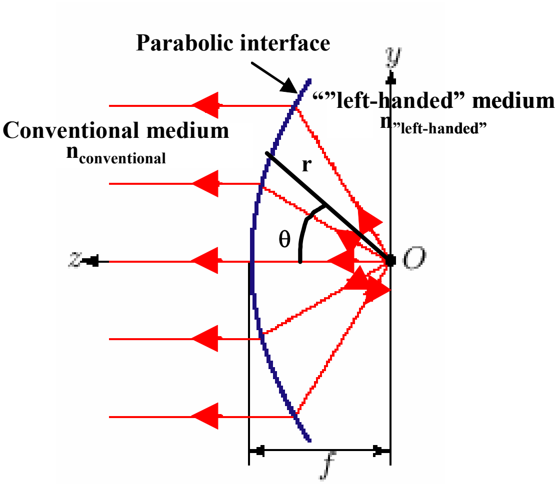

Fig. 1: Concept of the transformation from cylindrical to plane wave

The parabola is a ubiquitous shape in electromagnetic applications, as for example the traditional parabolic reflectors with feeder for satellite communications. In this version of antennas the transmitted and the received waves always propagate on the concave side of the parabola. Nevertheless, in this case the parabolic interface, which is not a metallic surface, allows the refracted rays to reflect hence in a transmission from a cylindrical wave into a plane one from one side to the other as depicted in Fig. 1.
The condition to achieve this transformation, via Fermat’s principle, is that the focal distance *f* is

$$f = \frac{r \cdot (n_{\text{"left-handed"}} - n_{conventional} \cdot \cos(\theta))}{(n_{\text{"left-handed"}} - n_{conventional})} \qquad (1).$$

B. *Ideal “left-handed” lens*

In Fig. 2 the schematic of the theoretic structure is illustrated. The model is composed of the parabolic interface placed between the “left-handed” medium and the dielectric foam, which is inserted between the plates of the parallel plate waveguide. The examined waveguide is a rectangular two-plate waveguide with metallic side walls. The final exterior outline of the guide is terminated with an absorbent material (adapted load). The excitation is realised by a coaxial probe situated in the centre of the novel kind of planar lens. The operating frequency of the lens is in the frequency band of 12 GHz.

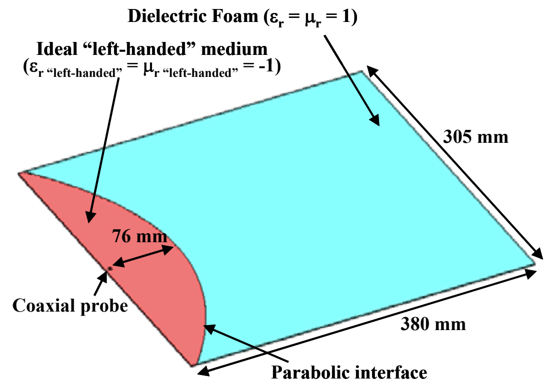

Fig. 2: Theoretic schematic of the ideal planar “left-handed” lens

In Fig. 3 and Fig. 4 the results of the simulation of the theoretic model are exposed in amplitude and in phase. An excellent conversion from spherical to plane wave is observed due to the condition of the equal electromagnetic densities of the two media applying an ideal “left-handed” medium ($\varepsilon_{r\ \text{"left-handed"}}=\mu_{r\ \text{"left-handed"}}=-1$). The very condition permits to adjust the interface between the two media in the way to avoid undesired reflections in order to obtain a perfect transformation to a plane uniform wave front in amplitude and phase.

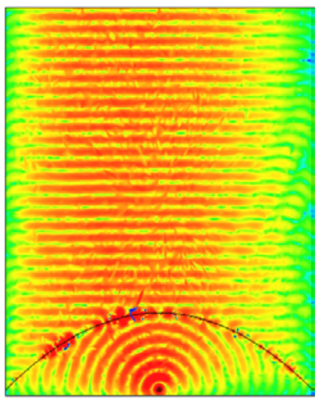

Fig. 3: Amplitude of the field distribution of the ideal “left-handed” lens

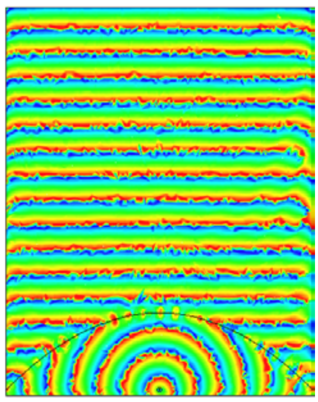

Fig. 4: Phase of the field distribution of the ideal “left-handed” lens

The ideal operating of the “left-handed” lens is the uniform propagation of the planar wave front in the inner parallel plate waveguide.

C. *Real "Left-handed" lens*

The great interest in the concept of the transformation from cylindrical to plane wave is to gain new types of applications by using "metamaterial" structures with adjustable parameters which behave as "left-handed" medium.

A structure in practice for this classification of lenses was proposed by Caloz, which performs as a "left-handed" medium [13]. This architecture called "mushroom" formation was first introduced by Sievenpieper [14] as high-impedance surface, where it was employed, because of its prohibited frequency band, for instance for suppression of spurious surface waves in planar antennas.

In [15] and [16], the "mushroom" arrangement was verified to be appropriate to present the effect of a positive/negative refractive index in its pass band gained by adequate designed parameters. Thus, it may be an alternative for "left-handed" media in terms of novel species of lenses [17].

In Fig. 5 this very texture is presented which is composed of arrays of microstrip patches connected to the ground plane by periodic vias pervading the dielectric substrate.

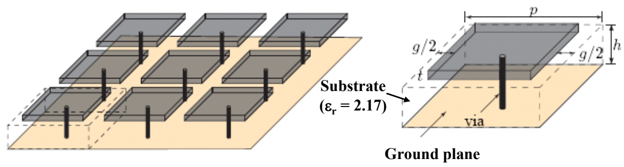

Fig. 5: "Mushroom" structure

The "mushroom" skeleton is constructed over a substrate with $\varepsilon_r = 2.17$ and a thickness of h = 1.57 mm to reveal a "left-handed" comportment of which the earmark is the negative refractive index in the band of 12 GHz. This "mushroom" complex is advantageous because of being simple, low cost and easy to construct by planar technology metallic vias included.

In this paragraph, this configuration is applied, as it can be seen in Fig. 6, for the physical realisation of the "left-handed" planar lens as advanced version to feed parallel plate slot antennas, which creates a parallel plate front in the interior of the parallel plate waveguide.

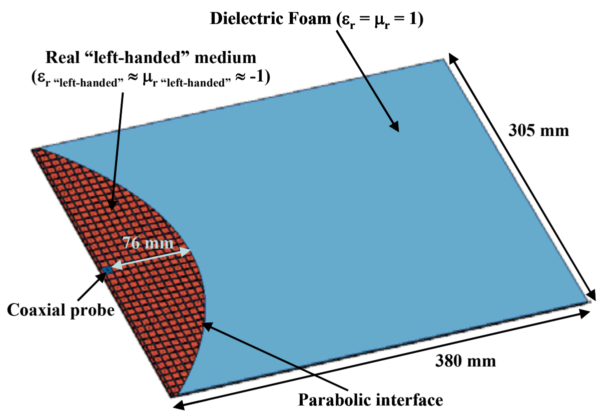

Fig. 6: Schematic in practice of the "left-handed" lens with the "mushroom" network

As it can be observed in Fig. 6, a large number of unit cells in this style is needed to reach a sufficient resolution in the transformation of the spherical wave, which emanates from the coaxial probe in the part in front of the plane wave.

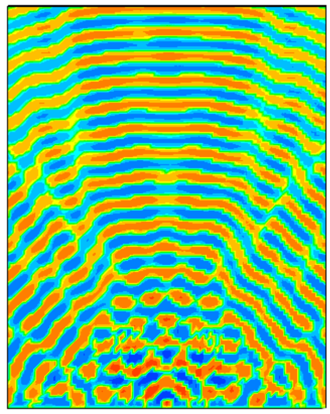

Fig. 7: Amplitude of the field distribution of the real "left-handed" lens

Fig. 7 elucidates the results of the simulation in amplitude of the field generated by the realised "mushroom" entity. The figure testifies a regular uniform conversion from cylindrical to plane wave in the centre of the parallel plate waveguide, whereas along the borders of the construction the plane wave front is not that uniform. This stems from the fact that the equal electromagnetic densities ($n_{\text{conventional}} = -n_{\text{"left-handed"}}$) of both media is not adapted perfectly. Hence, the interface and the two media are not absolutely conform they provoke undesired reflections, and for which the transformation in a plane wave is not accomplished in a totally uniform manner.

III. ANTENNA STRUCTURE

The basic configuration of the antenna is a two-plate waveguide with built up slots on the superior plate which are excited by plane wave. The slot antenna over the parallel plate waveguide, which is well indicated by its name, is set up by two metallic parallel plates which constitute the waveguide. The space in between is filled with air or any other dielectric material.. In this section, a planar wave front is established between the two conductors. In this manner, the alimentation is actualised from a side point of view in a unique sense of propagation. The plane wave front stimulates the radiation segment which is comprised of a planar array of resonant slots in the upper division of the wave guide. To prevent reflections produced by the individual slots, a radiant element is formed by three slots. The central is of the length close to resonance, the lateral slots are of minor length of which the function is to diminish the reflections of the primer one. In Figure 9 and Figure 10, a schematic of the prototype of the parallel plate slot antenna is given exhibiting linear polarization in the frequency and of 12 GHz, which will be constructed. This prototype will utilise the excitation circuit of the "left-handed" lens made up by "mushrooms" which we have analysed and designed in the former paragraph, and which has been described by Caloz [13]. The dimensions of the prototype are of 305 mm x 380 mm with metallic side walls between which is inserted dielectric material "foam" of 7.5mm thickness. The "left-handed" lens excited by a coaxial probe will generate a uniform plane wave front in the interior of the parallel plate wave guide.

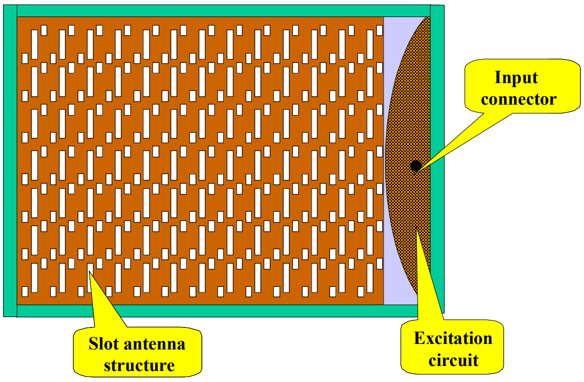

Fig. 9: Top view of the antenna with the plane "left-handed" lens as excitation circuit

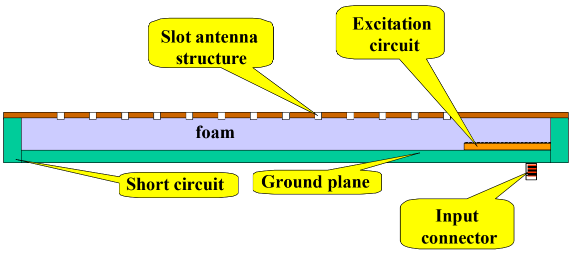

Fig. 10: Side view of the antenna with the plane "left-handed" lens as excitation circuit

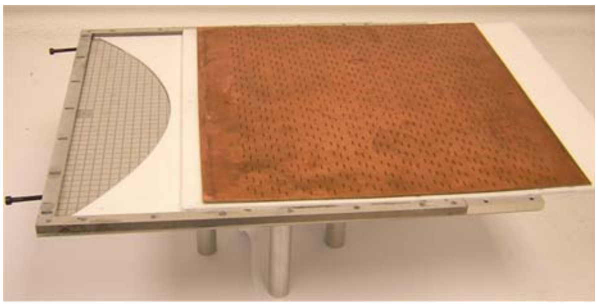

Fig. 11: Prototype of the slot antenna with the "left handed" lens

The results of the measurements of the real prototype excited by the planar "left-handed" lens in a planar slot antenna (Fig. 11) will be compared with the shown results of the simulations and they will be presented in the URSI/ACE meeting '05.

IV. CONCLUSIONS

A novel way to generate a plane wave front TEM in a parallel plate slot antenna has been demonstrated. A planar "left-handed" lens is thereby used, which is excited by a coaxial probe. The results of the simulations verify that a uniform field distribution in the inner double-plate waveguide can be reached. The consequence is an enhancement in the aperture of the illumination of the slots. Hence, by achieving to generate a planar wave front by this novel sort of lenses, we succeed in improving the radiation characteristics. This is in principle the efficiency of this class of antennas. While pursuing the traditional method to initiate a TEM mode in the aperture of the waveguide, the main advantage of using this topical manner of excitation is to overcome the reducing unwished effects and to acquire a chiefly uniform distribution of the field.

ACKNOWLEDGEMENTS

The authors like to thank CST (Computer Simulation Technology GmbH) for the use of the license of the software Microwave Studio v. 5.0 and NELTEC S.A for the samples of substrate NY used for the prototype in this work.

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